

# Adaptive Key Component Control of Nonlinear Evolving Flexible Structures

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## 1. Introduction

A critical element of successful on-orbit assembly of flexible space structures is the autonomous control of a structure during and after the connection of two or more components of its subsystem. In previous work [1]-[7], we have developed a new framework called Evolving Systems to describe the autonomous assembly of actively controlled subsystems into an Evolved System with a higher purpose.

The inheritance of stability is a crucial requirement for Evolving Systems of flexible space structures, which are actively controlled flexible structures that are autonomously assembled on-orbit. The actively controlled subsystem components which mate to form the fully Evolved System are designed to be stable in component form. However, as the stable subsystem components join, the connected components can become unstable. Thus, it is possible for a fully Evolved System comprised of stable components to fail to inherit the stability traits of its components.

We introduce an Adaptive Key Component Controller that uses an adaptive control law to restore stability in a system which would otherwise become unstable during assembly of the subsystem components. The adaptive control law does not require knowledge of the system's parameters, making it a good choice for many aerospace environments and applications which have poorly known system parameters. An illustrative example is given to demonstrate the adaptive key component controller design and use on an evolving flexible structure.

## 2. Problem Description and Mathematical Formulation

Consider Component Individual Actively Controlled Structures:

$$\begin{cases} \dot{x}_i = f_i(x_i, u_i) \\ y_i = g_i(x_i, u_i) \end{cases} \quad i=1, 2, \dots, L$$

with Performance Cost  $J_i$  and Lyapunov Function  $V_i$ . These are the building blocks of the Evolved Structure. When these individual structures are joined to form an Evolved System or Structure, this new entity becomes:

$$\begin{cases} \dot{x} = f(x, u) \\ y = g(x, u) \end{cases}$$

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with  $x = [x_1 \dots x_L]^T$ ,  $y = [y_1 \dots y_L]^T$ , Performance Cost Function  $J$ , and Lyapunov Function  $V$ .

The  $i^{\text{th}}$  component in the above Evolved System is given by:

$$\dot{x}_i = f_i(x_i, u_i) + \sum_{j=1}^L \varepsilon_{ij} f_{ij}(x_i, x_j, u_j); \quad 0 \leq \varepsilon_{ij} \leq 1$$

Note that when  $\varepsilon_{ij} = 0$ , the system is in component form and when  $\varepsilon_{ij} = 1$ , the system is fully evolved. As the system evolves, or joins together, the  $\varepsilon_{ij}$ 's evolve from 0 to 1.

Local control means dependence only on local state or local output information, i.e.,  $u_i = h_i(x_i)$  or  $h_i(y_i)$ . In general, the local controller on the  $i^{\text{th}}$  component would have the form:

$$\begin{cases} u_i = h_i(z_i) \\ \dot{z}_i = l_i(z_i, y_i) \end{cases}$$

Local control will be used to keep the components stable and meet the individual component performance requirements,  $J_i$ .

Once the system is fully evolved, the  $i^{\text{th}}$  component in the fully evolved system becomes:

$$\dot{x}_i = f_i(x_i, u_i) + \sum_{j=1}^L f_{ij}(x_i, x_j, u_j)$$

We say a subsystem property, such as stability, is inherited when the Evolved System retains the characteristic of the property from the subsystem component. Inheritance of the stability traits of subsystems is often desirable in Evolving Systems. However, inheritance of stability is not guaranteed in Evolving Systems.

### 3. Adaptive Key Component Control

Access to precisely known parametric values for flexible structure Evolving Systems is often unavailable, suggesting adaptive control laws might perform better than fixed gain control laws to restore stability in these systems. We develop the idea of an adaptive controller at a single key component to provide a practical solution to the problems described above. This paper introduces adaptive key component controllers to be used in nonlinear Evolving Systems which might fail to inherit stability and which have poorly known parameters. An approach using adaptive control laws in the key component is a good option which allows the system to benefit from the key component design [6] while not requiring knowledge of the component parameters. This paper will present a design method and the necessary conditions for adaptive key component controllers to restore stability in nonlinear evolving flexible structures using results from [6]-[8]. A flexible structure application will illustrate these results.

## References

1. Balas, M. J., Frost, S. A., and Hadaegh, F. Y., "Evolving Systems: A Theoretical Foundation," *Proceedings AIAA Guidance, Navigation, and Control Conference*, Keystone, CO, 2006.

2. Balas, M. J. and Frost, S. A., "An Introduction to Evolving Systems of Flexible Aerospace Structures," *Proceedings IEEE Aerospace Conference*, Big Sky, MT, 2007.
3. Frost, S.A. and Balas, M. J., "Stability Inheritance and Contact Dynamics of Flexible Structure Evolving Systems", *Proceedings 17th IFAC Symposium on Automatic Control in Aerospace*, Toulouse, France, 2007.
4. Balas, M.J. and Frost, S.A., "Evolving Systems: Inheriting Stability with Evolving Controllers", *Proceedings 47th Israel Annual Conference on Aerospace Sciences*, Tel-Aviv, Israel, 2007.
5. Frost, S.A. and Balas, M.J., "Stabilizing Controllers for Evolving Systems with Application to Flexible Space Structures," *Proceedings AIAA Guidance, Navigation, and Control Conference*, Hilton Head, SC, 2007.
6. Frost, S.A. and Balas, M.J., "Adaptive Key Component Controllers for Evolving Systems," Accepted *AIAA Guidance, Navigation, and Control Conference*, Honolulu, HI, 2008.
7. Frost, S.A. and Balas, M.J., "Adaptive Key Component Control and Inheritance of Almost Strict Passivity in Evolving Systems," Accepted *American Astronautical Society F. Landis Markley Astronautics Symposium*, Cambridge, MD, 2008.
8. Balas, M., Harvey, S. and Mehiel, E., "Nonlinear Adaptive Control with Persistent Disturbances, Accepted *AIAA Guidance, Navigation and Control Conference*, Honolulu, HI, 2008.